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STUDIES OF IONOSPHERIC PLASMA ELECTRODYNAMICS

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The research effort reported here has been focused on describing the morphology of plasma structures at low and high latitudes and seeking an understanding of the geophysical conditions that prevail during their occurrence and evolution.

Plasma structures, and irregularities in their associated electric and magnetic fields, have significant effects on the propagation properties of radio waves through the medium and on the dissipation of energy and momentum in the medium. By considering in detail the properties of plasma structures at low and high latitudes we will take steps toward accurate specification and prediction of the state of the medium and also contribute to exposing the important physics that couples the ionosphere with the atmosphere below and the magnetosphere above.

Plasma irregularities are a ubiquitous feature of the low-latitude nighttime ionosphere. These structures appear at the largest horizontal scales as gravity wave perturbations that may be 1000 km in extent. These perturbations provide the seat for instability mechanisms that may generate smaller scale irregularities that occupy spatial scales down to a few meters. These structures give rise to the well known spread-F phenomenon. Our work in this area has included the further study of various features of so-called spread-F bubble phenomena.

Also included in our studies is the beginning of work in ionosphere-magnetosphere coupling that is mediated by waves and currents in the ionosphere.

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STUDIES OF IONOSPHERIC PLASMA ELECTRODYNAMICS

Introduction

During this contract period our research effort has been focused on describing the morphology of plasma structures at low and high latitudes and seeking an understanding of the geophysical conditions that prevail during their occurrence and evolution.

Plasma structures, and irregularities in their associated electric and magnetic fields, have significant effects on the propagation properties of radio waves through the medium and on the dissipation of energy and momentum in the medium. By considering in detail the properties of plasma structures at low and high latitudes we will take steps toward accurate specification and prediction of the state of the medium and also contribute to exposing the important physics that couples the ionosphere with the atmosphere below and the magnetosphere above.

Plasma irregularities are a ubiquitous feature of the low-latitude nighttime ionosphere. These structures appear at the largest horizontal scales as gravity wave perturbations that may be a 1000 km in extent. These perturbations provide the seat for instability mechanisms that may generate smaller scale irregularities that occupy spatial scales down to a few meters. These structures give rise to the well known spread-F phenomenon. Our work in this area has included the further study of various features of so-called spread-F bubble phenomena.

Also included in our studies is the beginning of work in ionosphere magnetosphere coupling that is mediated by waves and currents in the ionosphere.

1. Seasonal and Longitudinal Distributions of Spread-F

This work extends our previous work and examines evidence for spread-F occurrence patterns being controlled by tropospheric disturbances. The premise of this work is that the occurrence of spread-F requires the presence of an initial perturbation (seed) rather than the seeds being omnipresent and spread-F resulting from appropriate growth conditions existing in the F-region. We assume that growth conditions are generally favorable and that the variability in the presence of seeds is largely responsible for the occurrence patterns of spread-F irregularities.

Through systematic analysis of longitude and seasonal distributions of irregularities we show that occurrence frequencies do not conform to the expectations arising from consideration of F-region growth conditions. Rather, the longitude and seasonal variations conform more closely to the development and decay of the intertropical convergence zone

and to the expected location of tropospheric convection cells. A summary of the longitude distributions of the irregularities that we study is shown in Figure 1. We conclude that that the geographic and seasonal variations in the location of tropospheric seed sources is a strong factor affecting the observed intensity and distribution of equatorial spread-F in the ionosphere.

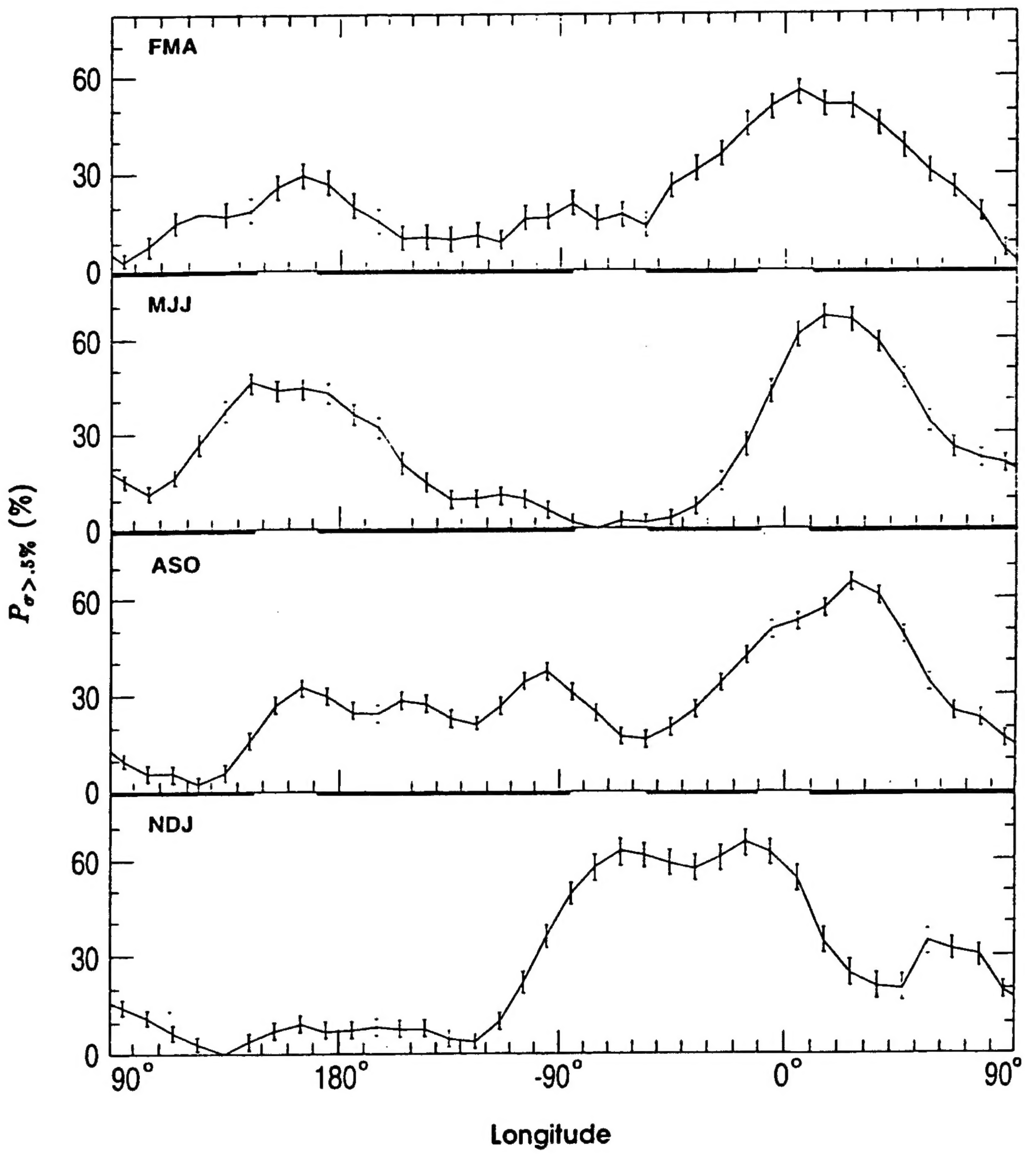

Figure 1. Observed longitude and seasonal distribution of irregularities suggesting a control from tropospheric sources.

2. Singular disturbances at low latitudes.

In addition to the appearance of spread-F bubbles in the nighttime ionosphere we also report on the appearance of singular plasma depeletions that represent large scale horizontal gradients in the plasma. These singular disturbances are distinguished from spread-F by their spatial isolation and by their unique vertical velocity signature. An example of the observed depletions and the associated vertical velocity is shown in Figure 2.

We show that such signatures can only be produced by a traveling disturbance that first raises the F-layer and then lowers it to its original location. Following the passage of this disturbance the layer is left unaffected but during its passage a horizontal plasma density gradient amounting to a change in density of a factor of 5 or more over spatial scales of a few hundred kilometers is produced. The source of this disturbance has not yet been identified. We believe the propagation velocities are too large to be of tropospheric origin and further consideration of magnetospheric or plasmaspheric sources is required.

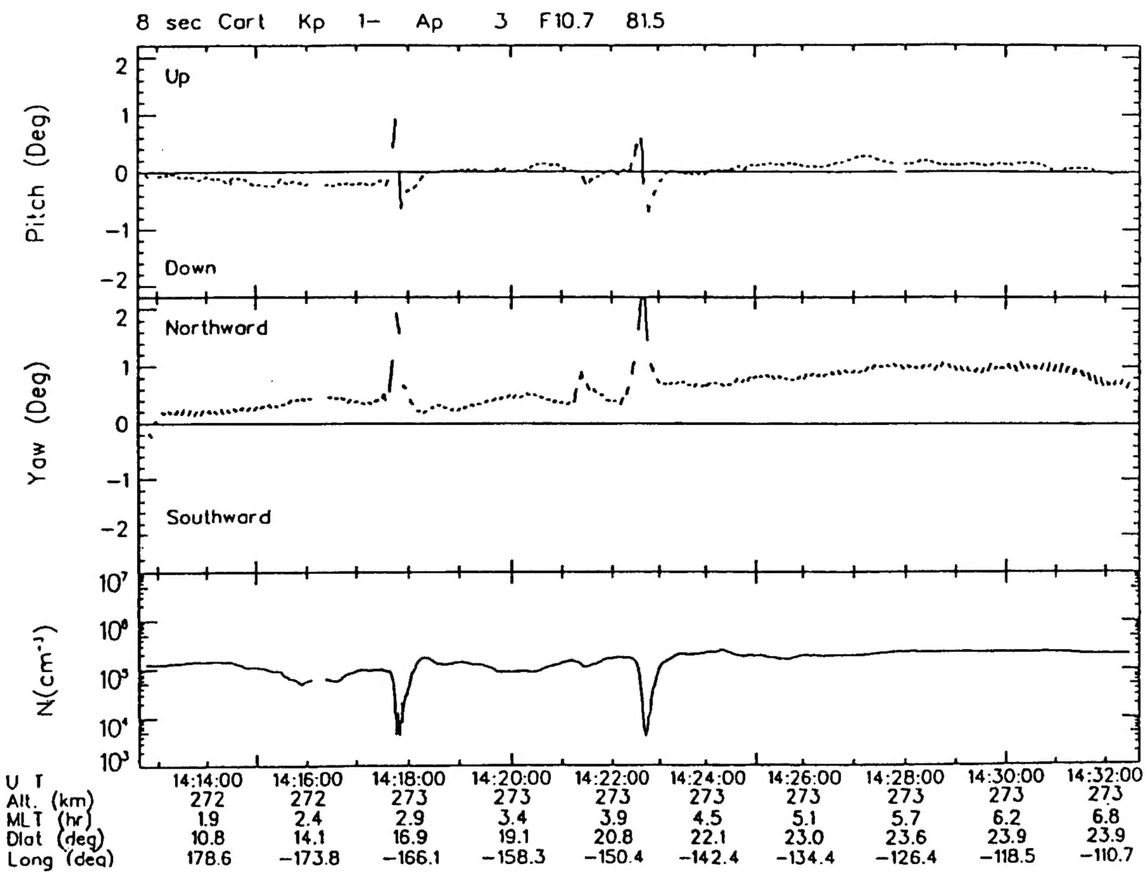

Figure 2. Drift and density signature associated with a singular plasma depletion.

3. Power Spectral Density in Spread-F

Once formed, shortly after sunset, spread-F bubbles remain for many hours into the early morning. During that interval, the associated irregularities may have dramatic effects on radio scintillations, but the severity of these effects will depend upon the power spectral density in the irregularities. Using an extensive data base from Atmosphere Explorer we have provided a description of the change in the spectral slope of irregularities as a function of time. Figure 3 shows the temporal evolution of the power spectral density of topside equatorial structures. We see that as a function of time a knee in the spectrum near 1 km scales is formed and preserved throughout the night. This knee is first formed by the preferential growth of structures with 1 km scale sizes. Following their growth, irregularities with scales near 1 km are preferentially preserved. This has profound effects on radio scintillations since 1 km scale structures are very effective in producing UHF scintillations. Further investigation of the location of 1 km scale structures in ionospheric spread-F shows that they tend to occur in the high density regions between bubble structures and not in the depleted bubble region itself. This will make such structures even more effective scintillation producers since the irregularities are associated with the largest electron densities.

4. Waves and Currents at high latitudes

In order to improve ionosphere-magnetosphere coupling models for magnetospheric specification it is necessary to discover the processes by which the ionosphere and the magnetosphere are coupled. This coupling may be accomplished through field-aligned currents or Alfven waves and in the case of current coupling the currents may be driven by a current source or a voltage source. By examining the relationships between ion drift and magnetic field perturbations at high latitudes we are able, in many cases, to distinguish between these different coupling processes. Figure 4 shows the effective conductivity derived from the ion drift and magnetic field perturbations for different locations and seasons. From analysis of this and other data we discover that field-aligned currents are important couplers near the dayside cusp and in the nightside auroral zone. On the dayside the currents arise primarily from a voltage source while on the nightside a current source is evident. In the midnight auroral region and the low latitude cusp region there exists strong evidence for coupling by Alfven waves. These wave sources are most evident when the interplanetary medium is changing and during the development of magnetospheric substorms.

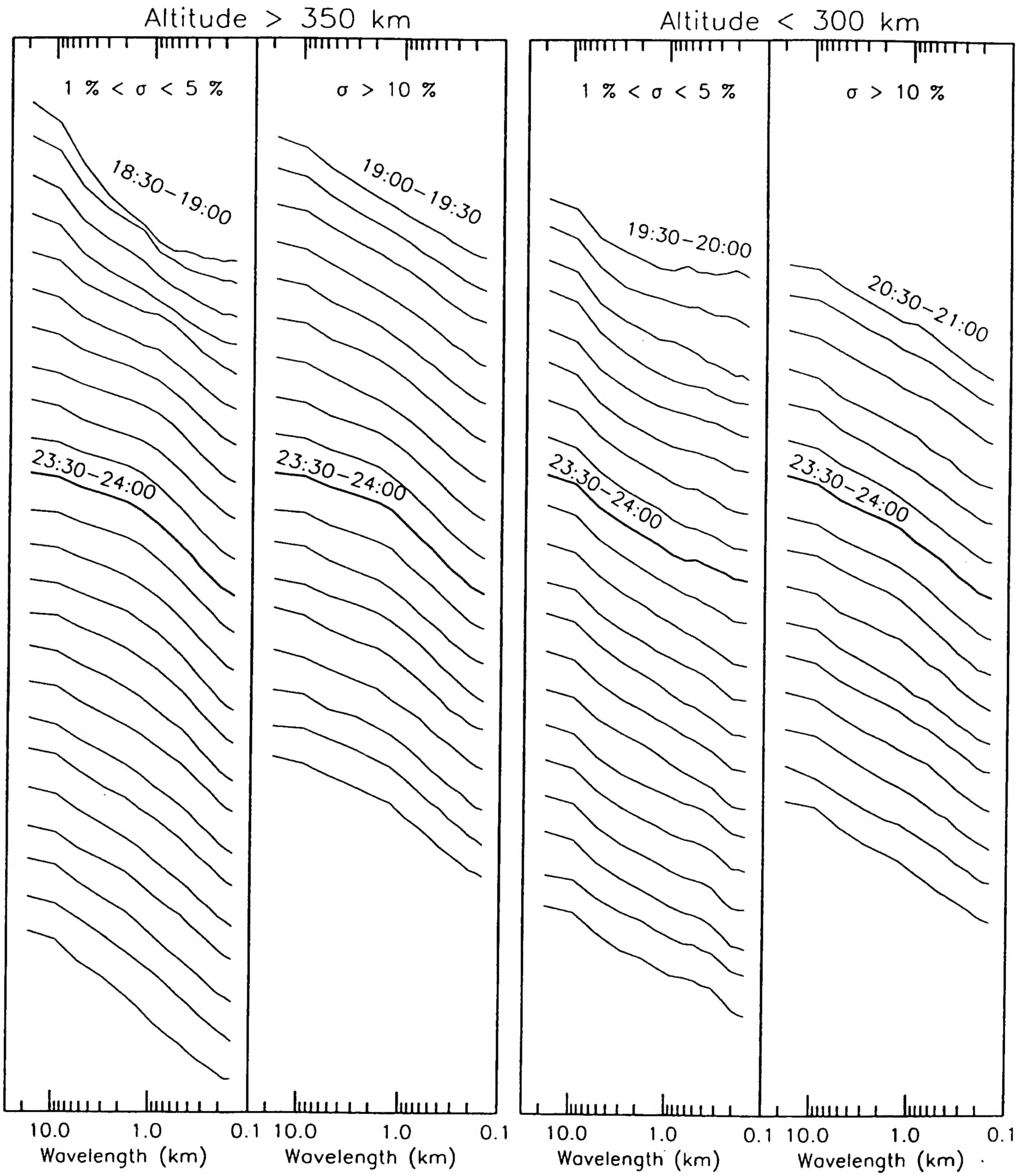

Figure 3. Temporal evolution of power spectral densities in spread-F structures observed above 350 km and below 300 km altitude.

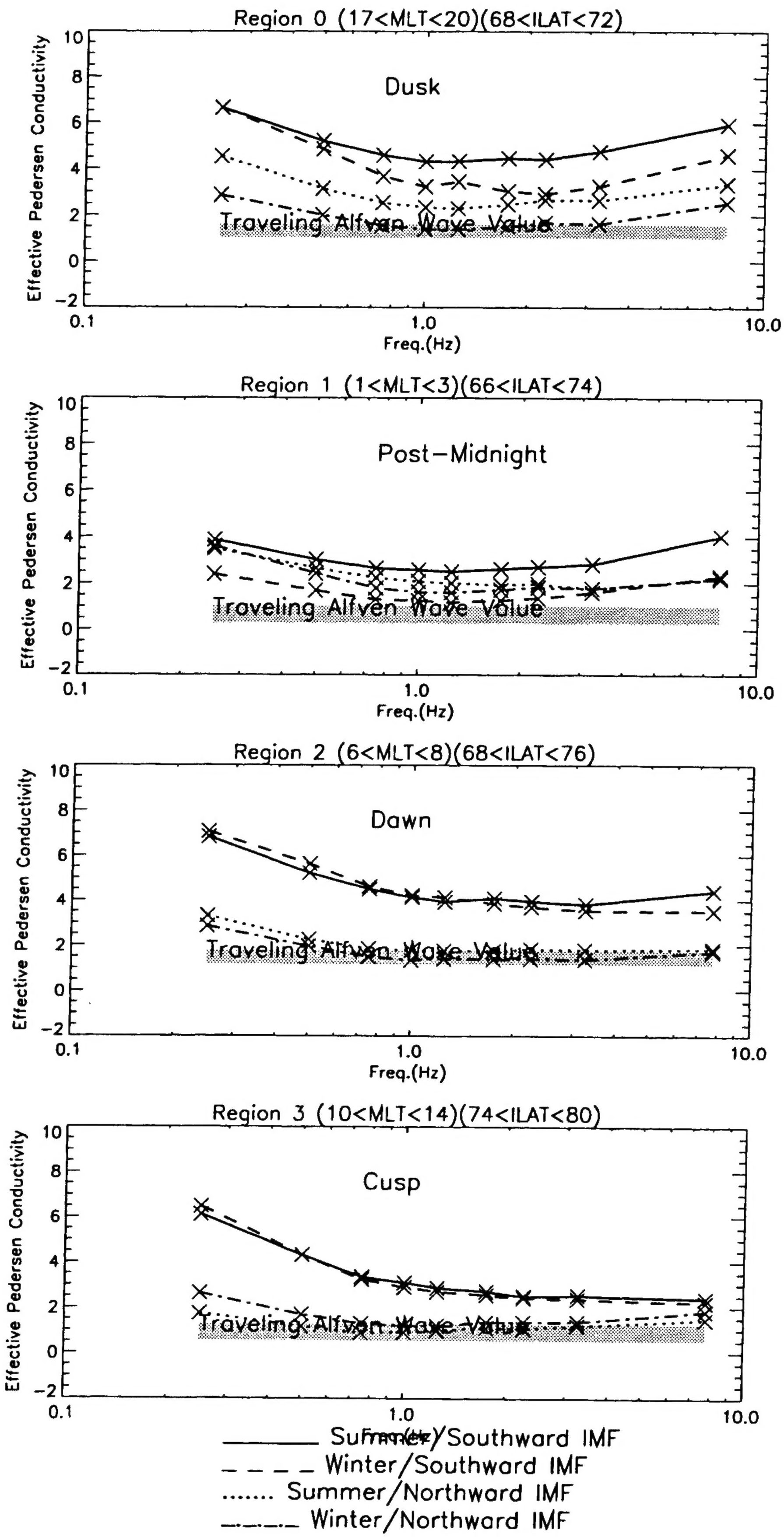

Figure 4. Effective Pedersen Conductivity showing variations between expected Pedersen value and the Alfven impedance in different regions.

Publications

The work described above has been systematically published in the leading journals in our field. Titles and abstracts of this published work are given below.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 103, NO. A12, PAGES 29,119–29,135, DECEMBER 1, 1998

Occurrence of equatorial F region irregularities: Evidence for tropospheric seeding

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Abstract. We present a new gap-free version of the seasonal and longitudinal (s/l) variations of P_{EFI}, the equatorial F region irregularity (EFI) occurrence probability, based on data from the AE-E spacecraft. The agreement of this and three earlier partial P_{EFI} patterns verifies all four. We reinterpret another earlier gap-ridden pattern, that of $\overline{D}_{\mathrm{RSF}}$, a topside ionogram index of average darkening by range spread F. We compare it with P_{EFI} and, using ionosonde radio science considerations, we conclude that $\overline{D}_{\mathrm{RSF}} = P_{\mathrm{EFI}}$ times a factor depending on the average number of topside plasma bubbles visible to the ionosonde. The s/l variations of $\overline{D}_{\mathrm{RSF}}$ thus imply s/l variations in the average spacing of bubbles, whose seeds have an occurrence probability pattern P_{seed}. For discussion we assume $P_{\mathrm{EFI}} = P_{\mathrm{inst}}P_{\mathrm{seed}}$, where P_{inst} is the pattern of F region instability. The P_{EFI} pattern, which is by definition independent of seed and/or bubble spacing, is far too complex to be explained by the dominant paradigm, that of changes in P_{inst} by simple changes in the F region altitude and/or north-south asymmetry. We examine evidence behind this dominance, and find it unconvincing. Both the asymmetry and sunset-node/altitude hypotheses of 1984 and 1985, respectively, seem to be partly based on misunderstood data, and their features appear displaced in time and space from those of our repeatable P_{EFI} pattern. In contrast, if P_{seed} variations influence the P_{EFI} pattern and depend on thermospheric gravity waves from tropospheric convection near the dip equator, then the seasonal maxima (minima) of P_{EFI} could be explained, since they all occur above relatively warm (cold) surface features, where convection is maximal (minimal). Also, the hypothesis of the dominance of the P_{seed} term could explain an unusual December/January P_{EFI} maximum in the deep, wide, normal Pacific minimum in the one data set obtained in El Niño years. Based on the experiments we consider, we predict that the s/l variations of P_{seed} will be found to be similar to those of P_{EFI}, and largely to explain them. Finally, we find reasons, based on the similarity of the $\overline{D}_{\mathrm{RSF}}$ variations to s/l patterns of the average scintillation index, for not using, as is commonly done, such scintillation patterns as substitutes for P_{EFI} or P_{inst} patterns.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 103, NO. A3, PAGES 3969–3981, MARCH 1, 1998

Equatorial density irregularity structures at intermediate scales and their temporal evolution

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Abstract. We examine high resolution measurements of ion density in the equatorial ionosphere from the AE-E satellite during the years 1977-1981. Structure over spatial scales from 18 km to 200 m is characterized by the spectrum of irregularities at larger and smaller scales and at altitudes above 350 km and below 300 km. In the low-altitude region, only small amplitude large-scale (λ>5 km) density modulations are often observed, and thus the power spectrum of these density structures exhibits a steep spectral slope at kilometer scales. In the high-altitude region, sinusoidal density fluctuations, characterized by enhanced power near 1-km scale, are frequently observed during 2000-0200 LT. However, such fluctuations are confined to regions at the edges of larger bubble structures where the average background density is high. Small amplitude irregularity structures, observed at early local time hours, grow rapidly to high-intensity structures in about 90 min. Fully developed structures, which are observed at late local time hours, decay very slowly producing only small differences in spectral characteristics even 4 hours later. The local time evolution of irregularity structure is investigated by using average statistics for low- ($1\%<\sigma<5\%$) and high-intensity ($\sigma>10\%$) structures. At lower altitudes, little change in the spectral slope is seen as a function of local time, while at higher altitudes the growth and maintenance of structures near 1 km scales dramatically affects the spectral slope.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 104, NO. A1, PAGES 199–212, JANUARY 1, 1999

Regional, scale size, and interplanetary magnetic field variability of magnetic field and ion drift structures in the high-latitude ionosphere

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Abstract. Using data from the Dynamics Explorer 2 satellite's ion drift meter and magnetometer, we have examined fluctuations in the high-latitude velocity and magnetic field structure to better understand the coupling between the magnetosphere and ionosphere. Our study examines perturbations in the frequency range from 0.25 to 8 Hz, equivalent to static scale sizes between about 30 and 1 km. Seasonal variations in the perturbations at large-scale sizes indicate that magnetosphere-ionosphere coupling is dominated by static currents. These static currents display behavior consistent with a current driver in the auroral zone and a voltage driver in the cusp. In the frequency range 0.6 to 1.5 Hz the magnetosphere-ionosphere coupling is significantly influenced by Alfven waves with the high-frequency range extending up to 8 Hz in the cusp.